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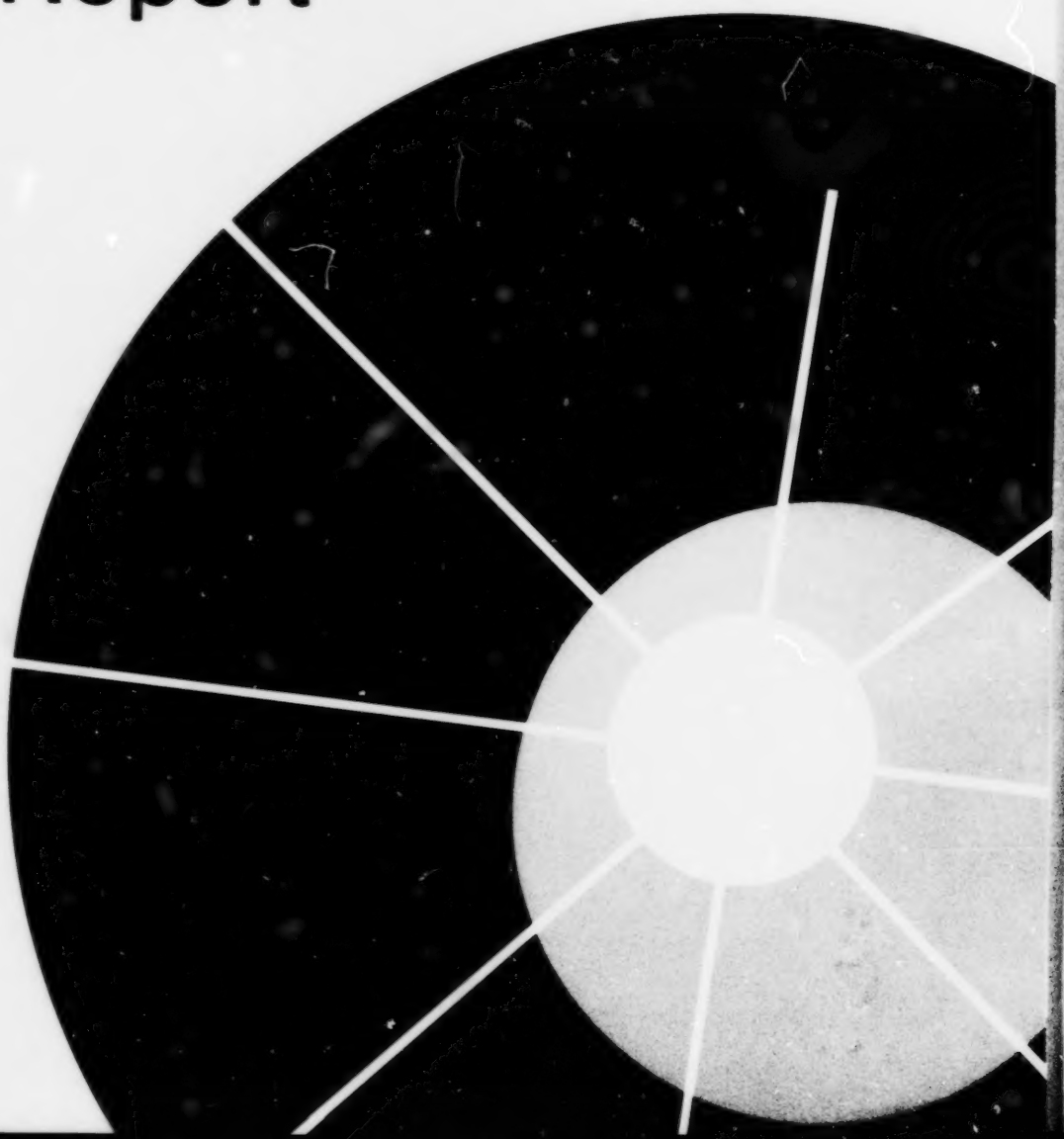
Canada - Saskatchewan Renewables — Conservation Demonstration Program

Final Report



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CANADA-SASKATCHEWAN CONSERVATION AND RENEWABLE ENERGY DEMONSTRATION AGREEMENT

On March 18, 1980, the governments of Canada and Saskatchewan entered into a Conservation and Renewable Energy Demonstration Agreement. The Agreement, which terminates March 31, 1984, funds the development and demonstration of a wide range of conservation and renewable energy technologies. The program is funded on an equal cost-shared basis by Canada and Saskatchewan, and is administered by Saskatchewan.

The objectives of CREDA are:

- To develop and demonstrate promising new technologies which exploit renewable energy resources, conserve energy, or make its use more efficient;
- To create employment in new or existing industries;
- To develop broad public awareness of the potential of renewable energy and energy conservation technologies.

This report outlines the results of a project funded by the Government of Saskatchewan as represented by Saskatchewan Energy and Mines, and the Government of Canada as represented by Energy, Mines and Resources Canada, under the terms of the Renewables-Conservation Demonstration Program, and contracted with the party identified herein.

However, neither the Government of Saskatchewan as represented by Saskatchewan Energy and Mines, nor the Government of Canada as represented by Energy, Mines and Resources Canada, accept liability for any errors, omissions, or inaccuracies that may; be included in or derived from this report, nor do they assume any liability with respect to the use of, or actions resulting from the use of, any information contained in this report.

Geothermal Project — Phase II A

Final Technical Report
on a Renewables-Conservation Demonstration Program Project

Conducted By

The University of Regina

And Supported By

Saskatchewan Energy and Mines
and
Energy Mines and Resources Canada

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Report FP-8

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UNIVERSITY OF REGINA GEOTHERMAL PROJECT
Phase IIa
WORK PRELIMINARY TO DRILLING OF DISPOSAL WELL AND
BUILDING OF PIPELINE

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ABSTRACT

A geothermal project is underway at the University of Regina to investigate and demonstrate within the western Canadian context the economic usage of the immense amount of low-grade geothermal energy that is available in deeply buried sedimentary rocks. In Phase I of the project, a 2200 m well drilled on the university campus revealed a good water supply (100 m^3/hr.) with 58.5°C (137°F) wellhead temperature. To complete the system and demonstrate usage of the energy in a building or buildings at the University of Regina, a disposal well with connecting pipeline is required (Phase IIb). Also required for demonstration purposes are suitable retrofitted heating facilities within the mechanical rooms of one or more buildings (Phase IIIa)

In this report on Phase IIa of the project, we describe the methodology, information acquired and analyses made on several tasks. The most important findings are:

1) The spacing between disposal and production wells of the doublet must be sufficient to prevent excessive cooling at the production well but there is real advantage to keeping this spacing as small as possible. The objective is to reduce pipeline cost and maximize at the producing well the beneficial pressure that derives from the recharge of cooled water at the disposal well. A major finding is that we can reduce our original proposed spacing of 1,830 m to 1,000 m. In view of this, we strongly recommend a new location for the disposal well in Lsd 10-8-17-19 W 2nd, 1,000 m northeast of the existing Regina 3-8 well.

2) Our consultants' report showed that a geothermal retrofit consisting of additions only is technically feasible in four buildings on the University of

Regina Main Campus. The estimated cost (exclusive of the wellside system) is $630,000. Our analysis of their report indicates that the system when prudently operated could result in net savings of $80,000 per year.

We recommend that only the Heating Plant and Physical Education buildings be retrofitted. These two buildings will use about 60 percent of capacity of the well doublet at peak usage so that they will serve as a good demonstration facility. When a new building is constructed in the southeast part of the campus, it will be desirable to install geothermal energy in it from the ground up. Estimated capital cost of the two-building retrofit (exclusive of wellside costs) is $300,000 and it can be credited with net savings of $42,000 per year under present conditions.

The economic potential of geothermal energy in the most favourable parts of Saskatchewan and other provinces of Canada is very good, especially if sizeable facilities are installed from the ground up and if the load factor is high. Based on the background we now have, it appears that in the Estevan-Weyburn area, for example, a two-well system could have a capacity of 7.5 MW and deliver 108,000 x 10^6 Btu per year to a heat-using facility. The total capital cost of such a system (including wells and heating system costs that exceed those of a conventional system) is $3.77 million. Under current conditions, the net savings attributable to such a system could be $402,000 per year. The economics are fairly good even if energy costs accelerate only at the rate of inflation. If energy costs escalate more rapidly than inflation, the economic potential becomes very great indeed.

Even though the overall economics of the Regina project are not advantageous when wellside costs are included, continuation of the project is recommended for several reasons: 1) The results will be applicable both in Saskatchewan and elsewhere in Canada where the economics of geothermal energy

is, or soon will be, quite favourable; 2) For research, monitoring and demonstration, the University of Regina location is a very good one; and 3) A considerable investment in technical manpower and in dollars has already been sunk in the Regina project.

We propose that the Regina Geothermal Project be continued by completing Phase II (Installation of the wellside system) at an estimated cost of $1,150,000. We should also proceed with Phase IIIa (Demonstration of geothermal energy in retrofitted Physical Education and Heating Plant Buildings) at an estimated cost of $350,000.

UNIVERSITY OF REGINA GEOTHERMAL PROJECT
Phase IIa
WORK PRELIMINARY TO DRILLING OF DISPOSAL WELL AND BUILDING OF PIPELINE

1. INTRODUCTION

1.1 Background: The Regina Geothermal Project

Hot water occurs in deeply buried porous and permeable sedimentary beds that are widely distrubuted in southern Saskatchewan and elsewhere in Canada. The size of this potential energy resource is immense. For all of Canada, the amount of energy is approximately 300 times the energy in our proven plus probable gas reserves of 5.2 trillion m^3. About a tenth of the Canadian resource is in Saskatchewan, underlying 190,000 km^2 southwest of a line between Melville and North Battleford.

Low-grade geothermal resources that resemble the resources in Saskatchewan and Canada have been used extensively for space heating for many years in France, Hungary, Soviet Republics and elsewhere. Usage in France in particular has grown rapidly since 1970 and by the 1990's it is planned to heat 300,000 apartment units with geothermal energy. On a smaller scale, low-grade geothermal projects are operative or planned for Denmark, Germany, Sweden, Italy, U.S.A., and elsewhere.

Before we can use this immense energy resource, there are technological and energy management problems peculiar to the Canadian-Saskatchewan region that must be investigated and solved. The Regina geothermal project involves a plan to solve some of these problems through research, development and demonstration. This pilot project has three phases:

I. Drilling and evaluation of an exploration-production well.
II. Drilling of the disposal well and building a connecting pipeline.
III. Demonstration of geothermal usage for space heating of a building at the University of Regina.

Phase I was completed by early 1980 and proved the viability and nature of the geothermal source at Regina. The results were generally favourable with good water producing reservoirs below 2,045 m depth, water temperature of about 60°C, and acceptable water chemistry. (Vigrass, 1980; 1982). In 1980, the University of Regina submitted a proposal for Phase II to the Canada/Saskatchewan Agreement on Renewables/Conservation which would essentially put in place the wellside system. Subsequently agreement was reached to proceed with Phase IIa which embraces certain work preliminary and preparatory to the drilling of the disposal well and building of the pipeline.

1.2 The Present Study (Phase IIa)

This report concerns the work done by the University of Regina under contract on Phase IIa of the Regina Geothermal project. The work includes tasks relative to installing power, shelter, recorders, and cathodic protection at the existing U of R Regina 3-8-17-19 well (hereafter referred to as the Regina 3-8 well). It also includes tasks necessary for the location and drilling of the disposal well and a task to conduct a pre-design investigation of use of the geothermal energy at the University of Regina. The purpose of the report is to disclose and record the details of the work done and to demonstrate that preparations are essentially complete for the drilling of the disposal well.

In this report, a summary with conclusions and recommendations is followed by a section on the project objectives and listing of tasks. This is followed by a summary of methodology, technical information obtained and the interpretive analysis completed by task. Following this is a discussion of the results, including a summary of the problems and successes associated with the work. Justification for continuation of the work and plans for Phase IIb follow. The report closes with a conclusion and list of references cited, followed by appendices that contain details of the work not suitable for inclusion in the body of the report.

The work was done by people at the University of Regina and by others outside of the University of Regina under agreement or subcontractual arrangement (see list of contributors). The work was authorized by contract with Saskatchewan Mineral Resources (Energy and Mines) on March 6, 1981.

The major problems addressed by the report are: i) Do we proceed with Phase IIb and Phase III? ii) If the answer to i) is affirmative, how do we proceed?

2. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

1. The amount of low-grade geothermal energy available in deeply buried sedimentary rocks in Saskatchewan and Canada is immense. Energy resources of similar nature have been used for space heating and other usages elsewhere, particularly in France, Hungary and the Soviet Republics.

2. Usage of the energy in Saskatchewan and Canada involves technological and management adaptations through a program of research, development and demonstration.

3. The Project has three phases:

I. Drilling and evaluation of an exploration-production well.
II. Drilling of a disposal well and connecting pipeline.
III. Demonstration of geothermal usage in a building or buildings at the University of Regina Main Campus.

4. Phase I has been successfully completed revealing a good water supply well (about 100 m^3/h) at a well head temperature of 58.5°C and acceptable water chemistry.

5. This report concerns Phase IIa which embraces certain work preparatory to the drilling of the disposal well and building of the connecting pipeline.

6. Certain tasks performed under Phase IIa were required to maintain the Regina 3-8 well (water supply well) in good order, to further the collection of data, and to proceed with Phase IIb of the project (completion of the wellside system).

7. We have installed an instrument shelter and power at the Regina 3-8 well. Water level fluctuations in the standing well have a considerable range (9.2 m to 16.5 m below surface) but are of unknown origin. In co-operation with Saskatchewan Research Council, we are installing a better water level recording device to investigate this phenomenon.

8. Co-operating workers installed a cathodic protection system to protect from external corrosion the surface and production casing at the Regina 3-8 well. The system, which includes anode test beds and allowance for determining whether well casings are protected fully, is operating satisfactory. Monitoring of the system should be continued.

9. We have expended considerable effort in determining the optimum distance between the producing and disposal well for the Regina well doublet. Details of current assessment of reservoir parameters and design of a a mathematical-computer model are included in this report. The work is important because 1) the disposal well must be situated at such a distance that the water temperature in the production well is not reduced excessively over the design lifetime of the system (35 years) and 2) the distance between wells must be kept to a minimum: i) to reduce pipeline costs and ii) to maximize at the producing well the beneficial pressure that derives from injection of fluids at the disposal well.

10. For the Regina well doublet, the optimum distance has been determined to be 975 m to 1,025 m. This is very significantly less than our original proposal to locate the well 1,830 m distant.

11. We strongly recommend drilling of the disposal well in Lsd 10-8-17-19 W 2M (revised location). This is 1,000 m northeast of the Regina 3-8 well and on University of Regina property. This location requires the shortest pipeline route and no highway crossings.

12. As alternative but less desirable locations for the disposal well we recommend sites in Lsd 11-5-17-19 or Lsd 1-8-17-19.

13. Approval to dispose of salt water into the Basal Clastic Unit has been obtained for a well to be located in Lsd 1-6-17-19 W 2M. An amendment to this approval will be required if the disposal well is located in one of the revised locations.

14. We acquired petroleum and natural gas leases in the name of the University of Regina on lands surrounding the proposed Lsd 1-6 location. Mineral ownership around the revised sites does not require the leasing of offsetting mineral leases.

15. We have discussed pipeline routing with Wascana Centre Authority personnel and have been advised to file plans with them when routing is definite.

16. In consultation with our petroleum engineering consultant, a program has been designed and a cost estimate made for the disposal well. It is proposed to set long string casing to 2,060 m depth and complete the Basal Clastic Unit as 159 mm open hole to a depth of 2,230 m. A decision based on cost must be made whether we run larger production casing at the surface (to 245 m depth) with a lower cost pump or whether to go with the present casing program and a higher cost pump.

17. The estimated cost for the completed injection well (including pump test, injection string, and wellhead) is $702,500.

18. A Bid Sheet and Well Specifications for Standard Drilling Contract has been prepared along with specifications and a list of suppliers for services and materials. The tenders have not been issued pending final approval for drilling of the well.

19. A consultant's report (Novametric-McCartan) shows that a geothermal retrofit is practical in the U of R Heating Plant, Physical Education, College West and Administration-Humanities Buildings. Above -20°C, the geothermal system could supply virtually all the heat required for the four buildings. Below -20°C (900 hours per year), the existing centralized steam system would supplement the geothermal energy. The estimated cost of the retrofit (exclusive of the wellside system) is $630,000.

20. Our analysis of the consultant's report indicates: 1) There is economic advantage to operating the system for only 66 percent of the year (Sept. 21 - May 21); 2) Saved heat energy can be credited presently with $5.46 per million Btu's on a delivered basis; 3) The extra electrical energy

required to run the geothermal system is slightly lower than previously estimated. On these bases the present savings for a four-building retrofit is $80,000 per year (based on annual energy savings of $175,000, annual electrical costs of $55,000 and annual operating costs of $40,000). From the University side, the ratio of capital cost (exclusive of the wellside system) to annual savings is a respectable 7.8. If the energy costs are assumed to escalate at 20 percent per year compared to an inflation rate of 10 percent, the project would be credited with a surplus of $3,000,000 (1982 dollars) in 15 years if the interest rate averages 15 percent.

21. We recommend that geothermal retrofits be installed in the Heating Plant and the Physical Education Building only at this time. These buildings will serve as a good demonstration of use of the energy (60 percent of capacity at peak requirement) and, when a new building is constructed in the southeast part of the campus, it would be desirable from a demonstration and economic basis to install geothermal energy as the primary heating mode from the start. The estimated capital cost (exclusive of wellside system) is $298,000 for the two-building retrofit under present conditions, the retrofit can be credited with net annual savings of $42,000 (annual energy savings of $100,000, additional electrical energy of $32,000, operating cost of $26,000). From the University side, the ratio of capital cost to present net annual savings is a favourable 7.2.

22. On the assumption that the well side system will be completed, the U of R Physical Plant Department has included $300,000 for the retrofit in its 1983-84 and 1984-85 budget requests. These requests are currently being considered by the U of R Board of Governors and the Saskatchewan Universities Commission.

23. The most significant findings of Phase IIa are:

1) the finding that a distance between wells of 1,000 m is sufficient for a project lifetime in excess of 35 years;

2) the finding that retrofit of existing University buildings is technically feasible and possible at relatively low capital cost.

24. Several requirements must be filled early in Phase IIb:

1) amendment of permit to dispose; 2) permission from Wascana Centre Authority; 3) final decision on size of upper production casing;

4) selection of drilling contractor and suppliers of services and materials;

5) final design of wellside system and integration with secondary (heating) system.

25. The economic potential of geothermal energy in more favourable parts of Saskatchewan and other provinces of Canada is very good. This is especially so if geothermal energy is installed in sizeable facilities from the ground up and if the load factor is high. Based on the background that we now have, it appears that in a favourable area such as the Estevan-Weyburn area of Saskatchewan a two-well system could have a capacity of 7.5 MW (thermal) and deliver heat energy of 108,000 x 10^6 Btu/year. For such a two-well system, the total capital cost is estimated at $3.77 million and the net savings assessed at $402,000 per year (ratio of capital cost to first year savings of 9.4). The capital cost estimate includes completed wells, all the wellside system, and the cost of the secondary system in excess of the cost of a similar-size conventional heating system.

26. The economics of geothermal energy in favourable areas is good even if energy costs do not escalate at more than the general rate of inflation. For the Estevan-Weyburn example, with energy costs escalating at the inflation rate of 10% per year, with the cost of capital at 15% and an amortization

period of 15 years, a geothermal project would show a surplus of $575,000 in constant (1983) dollars at the end of 15 years.

27. For the Estevan-Weyburn example, if energy costs escalate at about 20% per year whereas the general inflation rate is 10%, assuming the cost of capital at 15% and a 15-year amortization period, the project would net a surplus of more than $20 million (1983 dollars) at the end of the 15 year amortization period.

28. Because there are areas in Saskatchewan and Canada where the economic potential for geothermal energy is good, the Regina Geothermal Project should be continued in order to investigate and demonstrate this energy form under western Canadian conditions.

29. It is recommended that the Regina Geothermal Project be continued by completing Phase II (Installation of the wellside system) and proceed with Phase IIIa (Demonstration of geothermal usage in retrofitted Physical Education and Heating Plant Buildings on the University of Regina Campus).

30. A work statement and cost breakdown is included in this report. Costs are estimated at $1,150,000 for completion of Phase IIb and at $350,000 for Phase IIIa. It is planned to complete Phase IIb by October 31, 1983. Work on Phase IIIa is planned for the summer periods of 1983 and 1984.

3. PROJECT OBJECTIVES AND LIST OF TASKS

Project objectives are to complete certain tasks that are required:

1) To maintain the Regina 3-8 well in good order;

2) To further the collection of data; and

3) To proceed with Phase IIb of the project (Completion of the Wellside System).

Tasks numbered 1 to 12 are required under the contract (see next section for fuller description).

Task No.	Work to be Performed
1	Install power, shelter and recorders at the existing Regina 3-8 well.
2	Design and install cathodic protection for the Regina 3-8 well.
3	Identify site for disposal well.
4	Obtain permission to dispose
5	Acquire minerals and acquire a surface lease.
6	Obtain permits, right-of-way for pipeline.
7	Design well programme, cost estimate.
8	Issue tenders for drilling.
9	Select drilling contractor.
10	Pre-design investigation of use of geothermal energy at U of R.
11	Preparation of final report.

In addition, permission was granted (April 19, 1982) for partial support of attendance at a geothermal conference at Florence, Italy, presentation of a paper at Florence, and visitations with British workers. This task is referred to as:

Task 12	Presentation of paper at international conference.

4. SUMMARY OF METHODOLOGY, TECHNICAL INFORMATION ACQUIRED AND INTERPRETIVE ANALYSES COMPLETED.

4.1 Task 1: Install power, shelter and recorders

Under subcontract, the University of Regina installed an insulated plywood instrument shelter (approximately 5 m diameter x 3 m high) about 12 m to the north of the Regina 3-8 well. The University of Regina Physical Plant installed underground service to this instrument shelter (No. 8 conductors). Presently available at the shelter is 208/120 VAC. With the installation of a transformer, the system could be converted to 480/277 VAC with a capacity of 25 to 30 kVA.

With the aid of Mr. Robert Herr of the National Hydrology Research Institute, a 138 kPa (20 psi) pressure transducer was installed in the standing well at about 16 m depth (5 m below water surface). The transducer utilizes a 10 V ripple-free power source and a HP strip recorder. Water levels were monitored from June 11, 1981, to July 3, 1981.

The monitoring system was set up mainly to record variations in water level due to barometric pressure changes and effects such as earth tides. The 138 kPa transducer proved quite unsatisfactory because of lack of sensitivity. At the slow chart speeds we wanted, the HP strip recorder was also quite unsatisfactory.

The short period that we did record indicated a surprising effect. In addition to the minor fluctuations in head that we anticipated, there was a drop in head of 2.5 m over the 22 day period. A regression analysis indicates a very strong linearity of the data points with a steady drop of 0.11 m per day. The most reliable part of this data plus other data that we have collected at odd times with a hand line is summarized in Appendix I. The data

indicates that, after disturbances due to pumping are allowed to settle down, the water level ranges at least between elevations of +559.5 and +566.8 m with a total range of at least 7.3 m.

At present (January, 1983) we are co-operating with Saskatchewan Research Council (Garth van der Kamp, Harm Maathuis) on installation of one of SRC's water level monitoring devices at the Regina 3-8 well. We are also co-operating with the University of Alberta Physics Department (Walter Jones, Jim Rogers) on using tiltmeters to detect earth tidal effects at the University of Regina Gravity Wave Detection Station at a location 20 miles southwest of Regina.

4.2 Task 2. Design and install cathodic protection at the Regina 3-8 well.

On behalf of the Energy Research Unit, Dr. John Postlethwaite of the Department of Chemical Engineering, University of Saskatchewan, conducted a cathodic protection survey and then designed and installed a cathodic protection system to protect from external corrosion the surface and production casing at the Regina 3-8 well. His report on these phases of the work is included as Appendix II. In addition to casing protection, there are two other objectives of the work:to study the criteria used to determine whether well casings are fully protected to the casing shoe and to compare the performance of conventional anodes (graphite and high silicon iron) with newer anodes (magnetite and platinized units). Ongoing monitoring has been carried out since Feburary, 1982, when the system became operational.

The cathodic protection of the Regina 3-8 casing comprises a 40 V, 50 A rectifier with automatic potential control, 21 anodes of variable composition, an anode terminal box, and a buried copper-copper sulphate reference

electrode. The various anodes -- which include 8 high silicon iron (2 types), 4 standard graphite, 4 magnetite, and 5 platinized anodes -- are used to test their performance in western Canadain soil. Performance of verticaly installed anodes will be compared with those installed horizontally. The system has been designed with maximum flexibility so that it can be used in a future study to determine whether well casings are fully protected (see Appendix II).

4.3 Task 3: Identify site for disposal well

University of Regina personnel have determined a desired distance between the disposal and production well from known reservoir and design parameters. Consultations have been held with SEM personnel regarding the location of the disposal well.

Both the disposal and production well will be completed with the entire Basal Clastic Unit open. Over time, the cooled waters injected into the disposal well will return through the underground reservoir (herein referred to as "the aquifer") and be produced at the production well. We wish to situate the disposal well at such a distance that the water temperature at the production well will not be reduced "excessively" over the "lifetime" of the well system. Quite arbitrarily we have decided that the producing waters should not be cooled more than 2°C over a 35-year lifetime. With this constraint in mind, it is desirable to keep the distance between wells to a minimum for two reasons:

1) To keep pipeline cost to a minimum, and
2) To maximize at the producing well the beneficial (positive) pressure that derives from injection of fluids at the disposal well (see, for example, Menjoz and Sauty, 1982).

The problem of determining this optimum (shortest) distance between the two wells of the doublet comprises two parts: a) Determining the properties of the Basal Clastic Unit reservoir in the region where the two wells are completed (Appendix III), and b) Constructing a model to predict the length of time that water above a certain threshold temperature can be produced from a given two well system (Appendix IV).

4.3.1 Reservoir Properties of Basal Clastic Unit at U of R Regina 3-8-17-19 Well.

Properties based on cores and logs. - The reservoir at the Regina 3-8 well is considered to be a five-layered reservoir between 2045 m and 2209 m, K.B. reference. Values of net effective thickness, porosity-thickness, average porosity, permeability-thickness, and intrinsic permeability given in Table 1 are based primarily on core analyses and secondarily on density and sonic logs. The core control is very good in the Winnipeg Formation (34 m cored, 126 samples analyzed), good for the basal Deadwood (6 m cored, 22 samples analyzed) and poor for the remainder of the Deadwood (9 m cored, 37 samples analyzed) where the porosities are based largely on log properties.

The common practice in groundwater studies is to use hydraulic conductivity (K) and transmissivity (T) rather than intrinsic permeability (k) and permeability thickness(kb). Values of K and T for the Basal Clastic Unit in the Regina area, both at a producing well (60°C) and at a disposal well (35°C), are shown in Table 2. The values are derived from Table 1 so they are based on cores and logs.

Specific storage (S_s) at 60°C and 35°C has been calculated using weighted average aquifer compressibility, average porosity and an assumed fluid compressibility (Appendix III). The parameter does not appear to be

Table 1: Summary of thickness, porosity and intrinsic permeability for five layers in Basal Clastic Unit at the U of R Regina 3-8-17-19 well. (Based on cores and logs).

	Depth (m)	Net Thick. (m)	Poro.-Thick (m)	Ave. Poro. -	Perm.Thick (md.-m)	Ave Perm.(md.)
Winnipeg	2,045 - 2,083	31.2	4.749	0.152	2,171	70
Upper Deadwood	2,090 - 2,108	13.9	1.554	0.112	1,445	104
Middle Deadwood	2,110 - 2,150	24.3	2,942	0.121	2,527	104
Lower Deadwood	2,115 - 2,190	23.5	2.996	0.127	2,444	104
Basal Deadwood	2,190 - 2,209	19.0	3.218	0.170	4,231	223
	Totals	111.9	15.459		12,818	

Note: Average permeability (md.) for each layer is a geometric average (see appendix III).

For a single Basal Clastic Unit reservoir (2045 - 2009 m):

Porosity-thickness of entire reservoir = 15.459 m
Overall weighted average porosity = 15.459/111.9 = 0.138
Permeability thickness of entire reservoir = 12,818 md.-m
Average permeability (for layers producing in parallel) = 12,818/111.9 = 115 md.

Table 2: Summary of hydraulic conductivities (K) and transmissivities (T) at 35°C and 60°C for the Basal Clastic Unit at the Regina 3-8 well. (Based on cores and logs).

	Net Thick.(m)	At 60°C K(ms^{-1}) (X 10^{-6})	At 60°C T(m^2s^{-1}) (X 10^{-5})	At 35°C K(ms^{-1}) (X 10^{-6})	At 35°C T(m^2s^{-1}) (X 10^{-5})
Winnipeg	31.2	1.25	3.91	0.83	2.60
Upper Deadwood	13.9	1.86	2.59	1.24	1.72
Middle Deadwood	24.3	1.86	4.52	1.24	3.01
Lower Deadwood	23.5	1.86	4.38	1.24	2.91
Basal Deadwood	19.0	3.99	7.58	2.65	5.04
Basal Clastic Unit	111.9	2.06	23.0	1.37	15.3

sensitive to fluid temperatures so that an average of the values calculated at 60°C and 35°C is shown in Table 3 along with the storativity (S) for each layer.

Adjustment of aquifer properties to pump tests. - Based on 6-hour pump tests, the working valves of properties for the entire aquifer (Basal Clastic Unit) at 60°C were calculated by Vigrass (1980, p. 35) as:

$$T = 2.29 \times 10^{-4}\ m^2 s^{-1}$$

$$S = 3.6 \times 10^{-3}$$

The determination of storativity using pump test data is in considerable doubt and it is suggested that the values of S from the previous section (based on core measurements) are more realistic. It is here suggested that the working value for S (Basal Clastic Unit) be revised to 5×10^{-4}.

Pump test results are likely to be more useful in determining T (transmissivity) than core-log analysis because: a) fracturing is difficult to evaluate in cores, b) much of the total aquifer was not cored and c) in part a geometric average permeability (transmissivity) was used but it is uncertain whether this is the correct model to use. It is here suggested that the working values of T be adjusted to conform to the most reliable pump test results , matching these results with the new value of S derived from the core-log analysis.

The adjustment of transmissivity is described in Appendix III using the observed water level at the end of a six-hour pump test. The result is that the new working value of T is 2.91 $m^2 s^{-1}$, somewhat greater than that indicated from core-log analysis alone. A summary of working values of net thickness, average porosity, storativity and transmissivities for all the layers is given in Table 4.

TABLE 3: Summary of specific storage (S_s) and storativity (S) for the Basal Clastic Unit at Regina 3-8 well (Based on core and fluid properties - see Appendix III)

Layer	Net Thickness (m)	S_s(x 10^{-6}) (m^{-1})	S(x 10^{-4})
Winnipeg	31.2	4.21	1.31
Upper Deadwood	13.9	1.92	0.27
Middle Deadwood	24.3	2.18	0.53
Lower Deadwood	23.5	2.40	0.56
Basal Deadwood	19.0	11.66	2.21
Basal Clastic Unit	111.9		

NOTE: The specific storage (S_s) for the entire Basal Clastic Unit calculated from α , β and an average porosity of 0.138 is 2.93 x $10^{-6}m^{-1}$. This gives a storativity (S) for the entire unit of 3.28 x 10^{-4}. The storativity derived by summing the component layers is 4.88 x 10^{-4} (average S_s = 4.36 x $10^{-6}m^{-1}$).

TABLE 4: Summary of working reservoir properties for Basal Clastic Unit reservoirs at the Regina 3-8 well

Layer	Net Thickness (m)	Ave. Poros.	S ($\times 10^{-4}$)	T($m^2 s^{-1}$) ($\times 10^{-4}$)
Winnipeg	31.2	0.152	1.3	0.5
Upper Deadwood	13.9	0.112	0.3	0.3
Middle Deadwood	24.3	0.121	0.5	0.6
Lower Deadwood	23.5	0.127	0.6	0.5
Basal Deadwood	19.0	0.170	2.3	1.0
	111.9	0.138	5	2.9

Note that transmisivities refer to Regina geothermal brine at 60°C having density of 1,058 kg m^{-3} and dynamic viscosity of 5.72×10^{-4} kg $m^{-1}s^{-1}$.

4.3.2 Modelling of the Regina geothermal well doublet

Mr. Keith Hutchence and co-workers at the University of Regina have developed a mathematical and computer model to predict breakthrough times for low-grade geothermal well systems in a single uniform aquifer with the wells having constant pumping rates and the injection water being at a constant temperature. A description of the basic model, some results, and a discussion of the successes and shortcomings are included as a separate report (Appendix IV). The printouts in the Hutchence report are for temperature distribution and hydraulic potential for the Basal Deadwood having the following parameters:

Basal Deadwood Net thickness = 19.0 m

Storativity 1.81×10^{-4} Transmissivity = $1 \times 10^{-4} m^2 s^{-1}$

Injection temperature 33°C Production Temperature 60°C

Pumping rate $8.01 \times 10^{-3} m^3 s^{-1}$ Porosity 0.17

Density of water 1,065 kg m^{-3}

Density of rock matrix (mineral grains) 2,650 kg m^{-3}

Heat capacity of the water 900 calories $kg^{-1} K^{-1}$

Heat capacity of the rock matrix 185 calories $kg^{-1} K^{-1}$

Hydraulic conductivity $5.26 \times 10^{-6} ms^{-1}$

Thermal conductivity 1 calorie $m^{-1} s^{-1} K^{-1}$

Distance between wells 1,000 m

Grid spacing 25 m

Time step size 0.5 years

Note that in the example given in the Hutchence report, the temperature at 900 m distance from the injection well (co-ordinate No. 36.00) is 59.97°C

after 30 years. In this vicinity, the arrival time (years since pumping started) varies approximately as the square of the distance travelled so that the first arrival of cold water would occur at 972 m from the injection well in 35 years.

The illustrations following (Figs. 1-7) are derived from a model somewhat improved from that of Appendix IV. Figures 1 to 4 concern the entire Basal Clastic Unit acting as a single reservoir. The distance between the discharge well and recharge well is 1,000 m and both are pumping steadily at 100 m^3h^{-1}. The aquifer properties are those shown in Table 4 ($S = 5 \times 10^{-4}$, $T = 2.9 \times 10^{-4}\ m^2s^{-1}$, Ave. porosity = 0.138; net thickness = 111.9 m).

Hydraulic potential in the well field does not change very much after about six months of steady pumping. Figure 1 shows the change in hydraulic head after 35 years as a result of production and re-injection. Note that the hydraulic head applies to the geothermal brine at 60°C and a density of 1,058 kg m^{-3}. Note also that the change in hydraulic pressure (drawdown at the discharge well and buildup at the recharge well) takes place relative to the original hydraulic surface adjusted to a temperature of 60°C. The original hydraulic surface (60°C) has been calculated at elevation +581.5 m (a static gradient test on April 8, 1980 suggests that it may be as high as +595 m).

Figure 1 shows that the drawdown at the pumping well is expected to be 140.5 m. To this must be added the frictional loss in casing and open hole, estimated to be 18 m. This means the pumping level throughout the life of the wells will not drop significantly below an elevation of +423 m (153 m below ground surface) and may, in fact, be higher than this. This pumping level is significantly higher than reported previously, mainly as a result of the interference effects between the discharge-recharge wells. Similarly the back pressure at the disposal well is expected to be less than previously

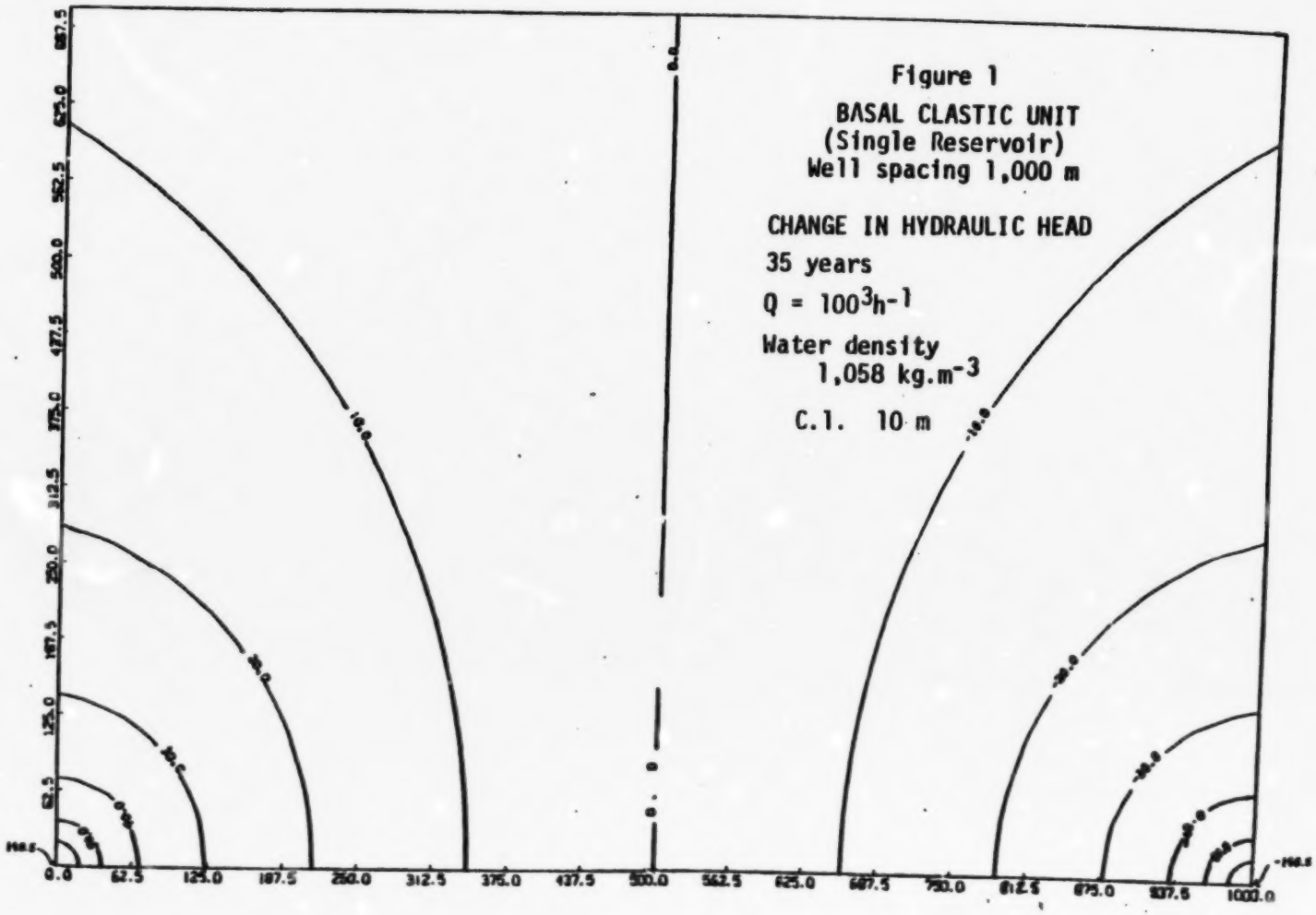


Figure 1
BASAL CLASTIC UNIT
(Single Reservoir)
Well spacing 1,000 m
CHANGE IN HYDRAULIC HEAD
35 years
Q = 100 m3h-1
Water density
1,058 kg.m-3
C.I. 10 m
0.0
62.5
125.0
187.5
250.0
312.5
375.0
437.5
500.0
562.5
625.0
687.5
750.0
812.5
875.0
937.5
1000.0

estimated: the back pressure at the ground surface (disposal rate 100 m^3h^{-1}) is now expected to be a maximum of 2800 kpa at the casing bowl. (This includes pressure required to overcome tubing friction). These changed predictions of pumping level and back pressure lessen the power requirements and result in improved economics for the the well system (see Section 4.10.2).

The next illustrations (Figs. 2, 3, 4) show temperature distribution in the Basal Clastic Unit assuming that it acts as a single aquifer having the hydraulic characteristics reported above. The water is removed at 60°C from a discharge well that is 1,000 m distant from a recharge well where the water is reinjected at 33°C. The thermal characteristics are: heat capacity of water and mineral respectively 900 and 185 calories kg^{-1} K^{-1}; thermal conductivity 1 calorie $m^{-1}s^{-1}$ K^{-1}. The grid spacing is 25 m and the time step size is 0.25 years. Figures 2, 3 and 4 show the temperature distribution in the aquifer at 15, 30 and 45 years. At the end of 15 years the injected water has advanced an estimated 445 m toward the production well, after 30 years it has advanced about 625 m and after 45 years it has advanced about 825 m toward the production well. Obviously, under the conditions stated, the lifetime of the doublet would be well in excess of 50 years.

Regarding the Basal Clastic Unit as a single aquifer results in the longest aquifer life because it assumes that the "front" of cold water advances evenly throughout the 175 m thickness of the aquifer. We believe that it is more realistic to regard the Basal Clastic Unit at Regina as a five layered aquifer each with differing hydrological properties. Table 5 shows the ratio of transmissivity to void space (T/porosity-thickness) for the five layers.

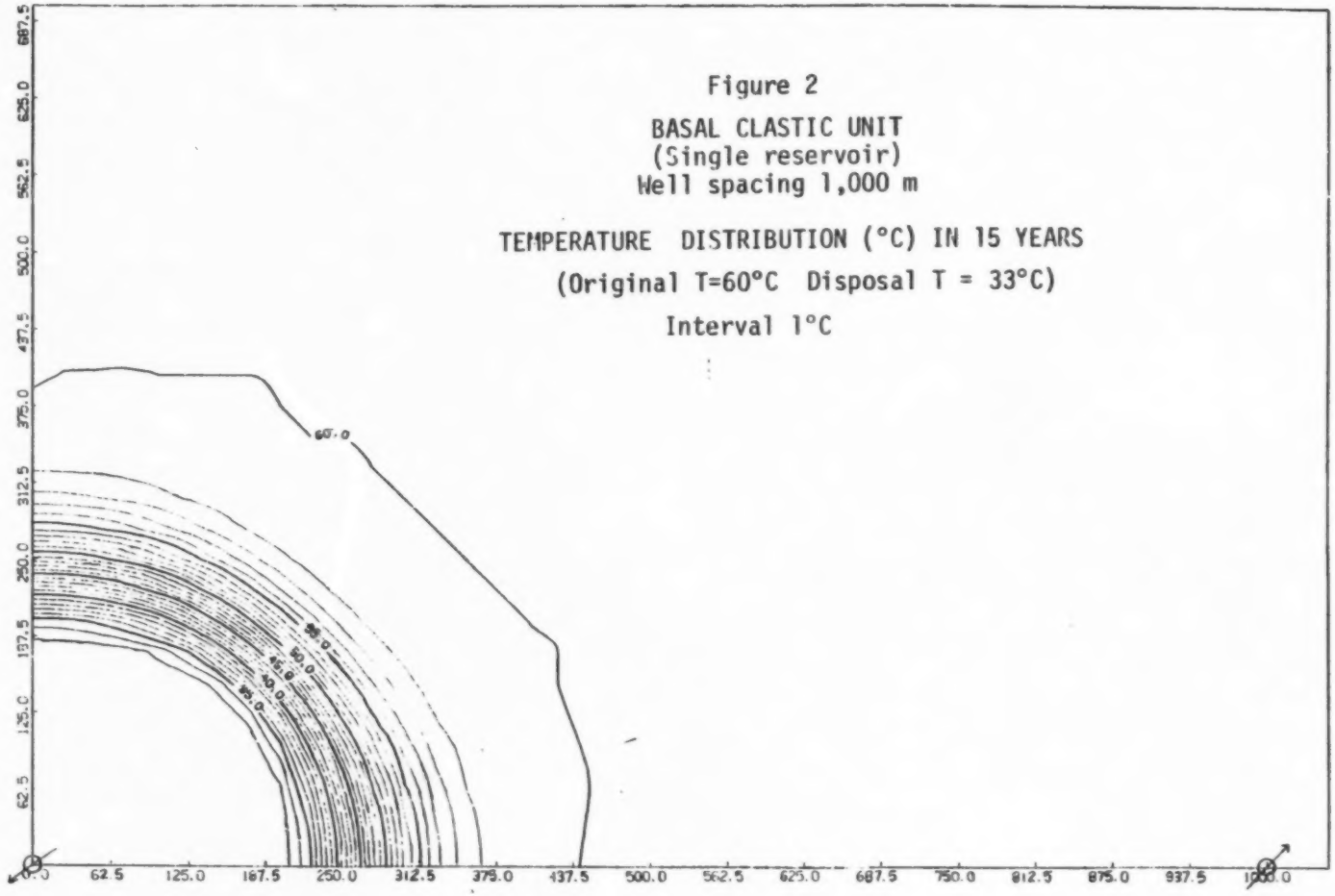


Figure 2

BASAL CLASTIC UNIT
(Single reservoir)
Well spacing 1,000 m

TEMPERATURE DISTRIBUTION (°C) IN 15 YEARS

(Original T=60°C Disposal T = 33°C)

Interval 1°C

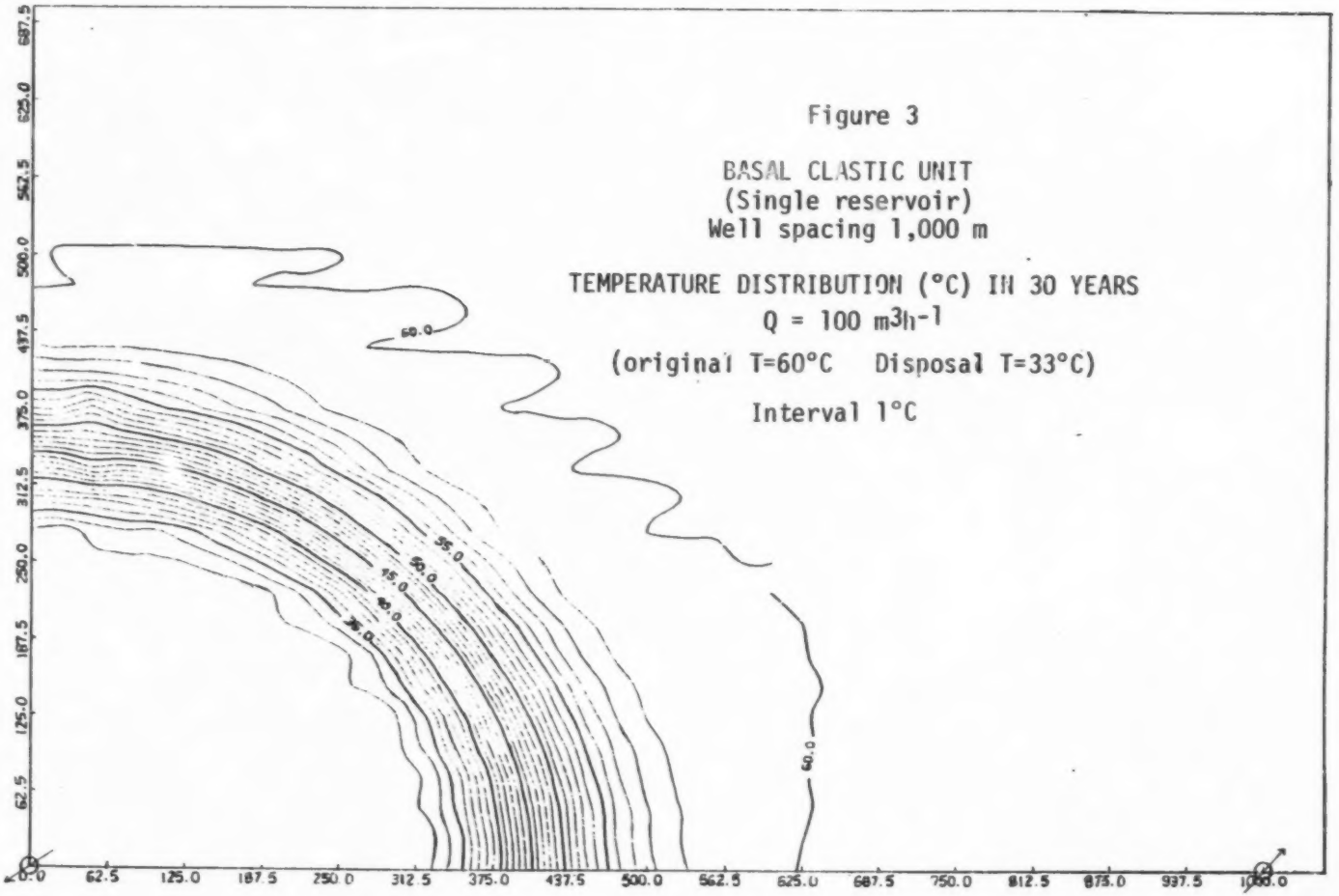


Figure 3

BASAL CLASTIC UNIT
(Single reservoir)
Well spacing 1,000 m

TEMPERATURE DISTRIBUTION (°C) IN 30 YEARS
Q = 100 m^3h^{-1}

(original T=60°C Disposal T=33°C)

Interval 1°C

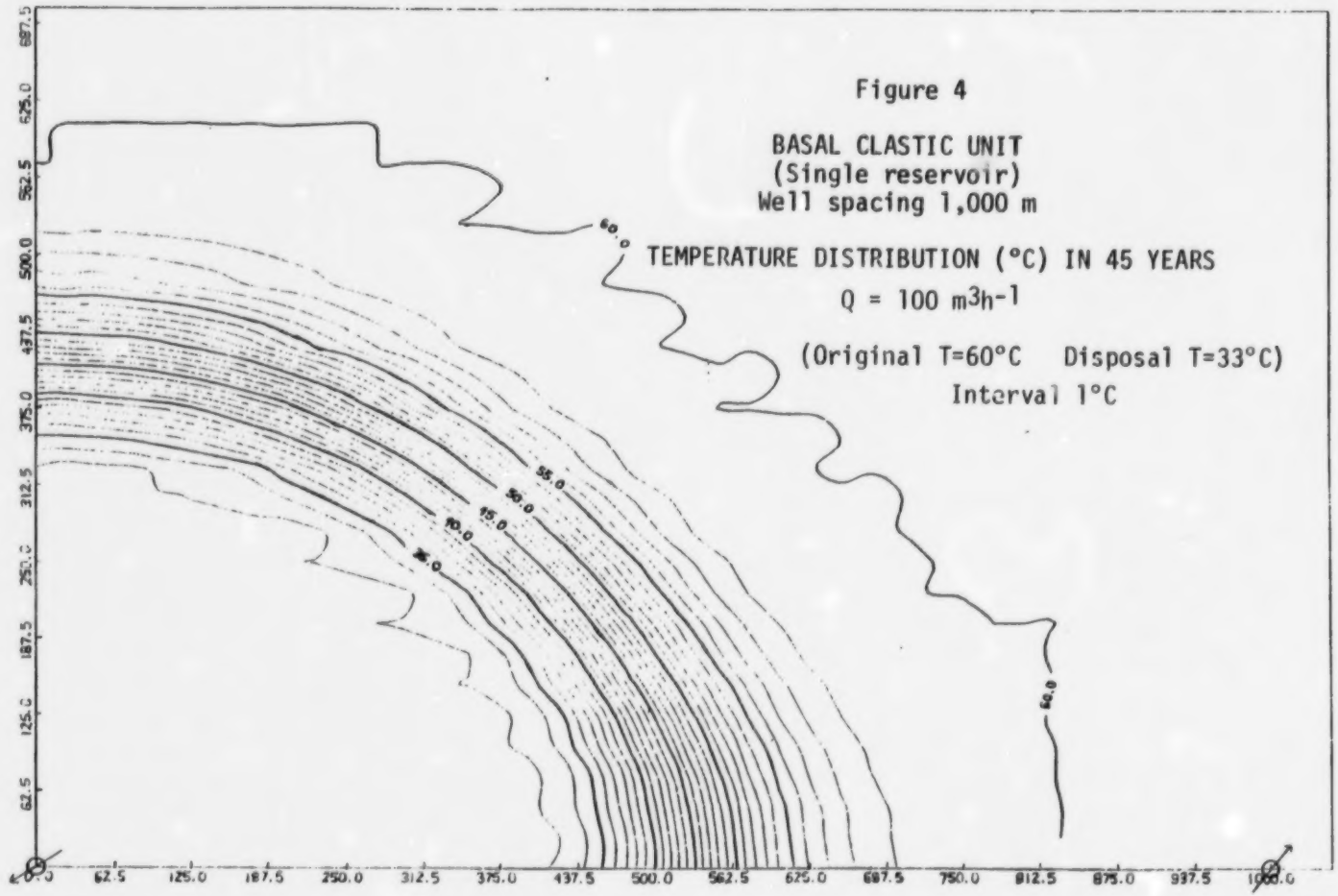


Figure 4

BASAL CLASTIC UNIT
(Single reservoir)
Well spacing 1,000 m

TEMPERATURE DISTRIBUTION (°C) IN 45 YEARS

Q = 100 m^3h^{-1}

(Original T=60°C Disposal T=33°C)
Interval 1°C

Table 5: Ratio of T/porosity thickness for the Basal Clastic Unit Regina 3-8 well.

Layer	1 T (m^2s^{-1} x 10^{-4})	2 Poros.-Thickness (m)	1 ÷ 2
Winnipeg	0.5	4.749	0.105
Upper Deadwood	0.3	1.554	0.193
Middle Deadwood	0.6	2.942	0.204
Lower Deadwood	0.5	2.996	0.167
Basal Deadwood	1.0	3.218	0.311
Basal Clastic Unit	2.9	15.459	0.188

These ratios show that the Basal Deadwood will produce (or accept) more water relative to the void space available than the other layers. In a doublet system, the cooled "front" would be expected to advance more rapidly in the Basal Deadwood than it would in the other layers. Temperature distribution in the Basal Deadwood therefore is likely to be the controlling factor in the life of the well doublet.

Calculation of the time to breakthrough of cooled water at the production well is complicated somewhat by the virgin vertical pressure distribution in the Basal Clastic Unit (Vigrass, 1980 p. 21-23, 60, 64). If the virgin hydraulic head was the same for all layers, the Basal Clastic Unit would produce 33 percent of the water at the discharge well because it has 33 percent of the total permeability capacity (4,231 md.-m for Basal Deadwood; 12,818 md.-m for total Basal Clastic Unit). The Basal Deadwood, however is a "low pressure" layer so it would be expected to discharge less than 33% during the earlier part of the doublet history (estimated 24%) but receive more than 33% at the recharge well (estamated 42%). As discharge and recharge proceeds, it is considered (but not yet demonstrated analytically) that the Basal Clastic Unit can be modelled for temperature distribution as though the discharge rate and recharge rate both amount to 33 percent of the total production.

Figures 5, 6 and 7 show models of temperature distribution for the Basal Deadwood after 35 years of continuous pumping at 33 m^3h^{-1}. The aquifer properties are those shown in Table 4 ($S = 2.3 \times 10^{-4}$, $T = 1 \times 10^{-4}$ m^2s^{-1}, Ave. porosity = 0.170, net thickness = 19.0 m). Water is removed at 62.5°C (note that it is 2.5°C hotter than for the entire unit because of its greater depth) and reinjected at 33°C. Thermal characteristics, grid spacing and time steps are the same as for the Basal Clastic Unit (Figs. 1-4). The spacing

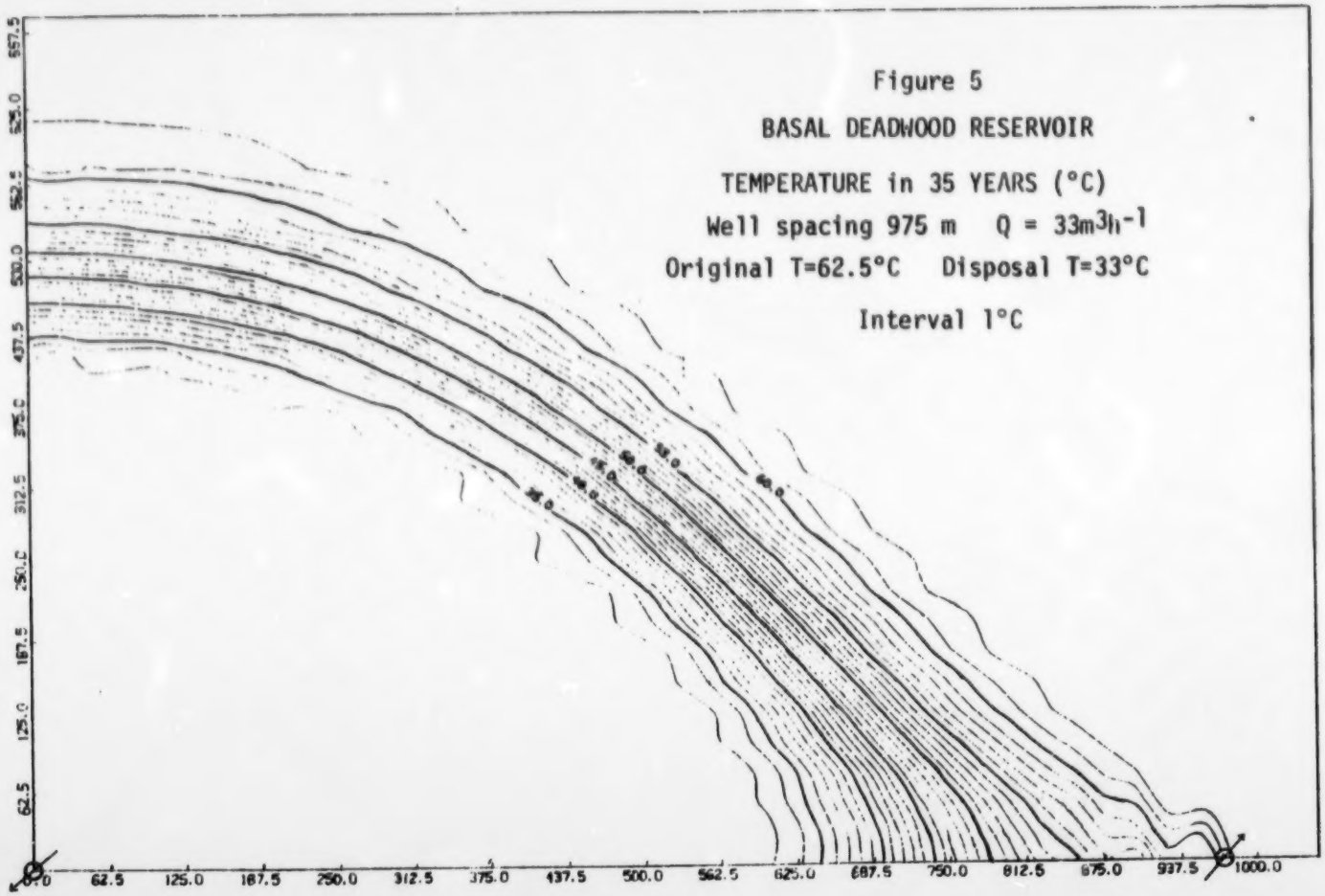


Figure 5
BASAL DEADWOOD RESERVOIR
TEMPERATURE in 35 YEARS (°C)
Well spacing 975 m Q = 33m3h-1
Original T=62.5°C Disposal T=33°C
Interval 1°C
62.5
125.0
187.5
250.0
312.5
375.0
437.5
500.0
562.5
625.0
687.5
750.0
812.5
875.0
937.5
1000.0

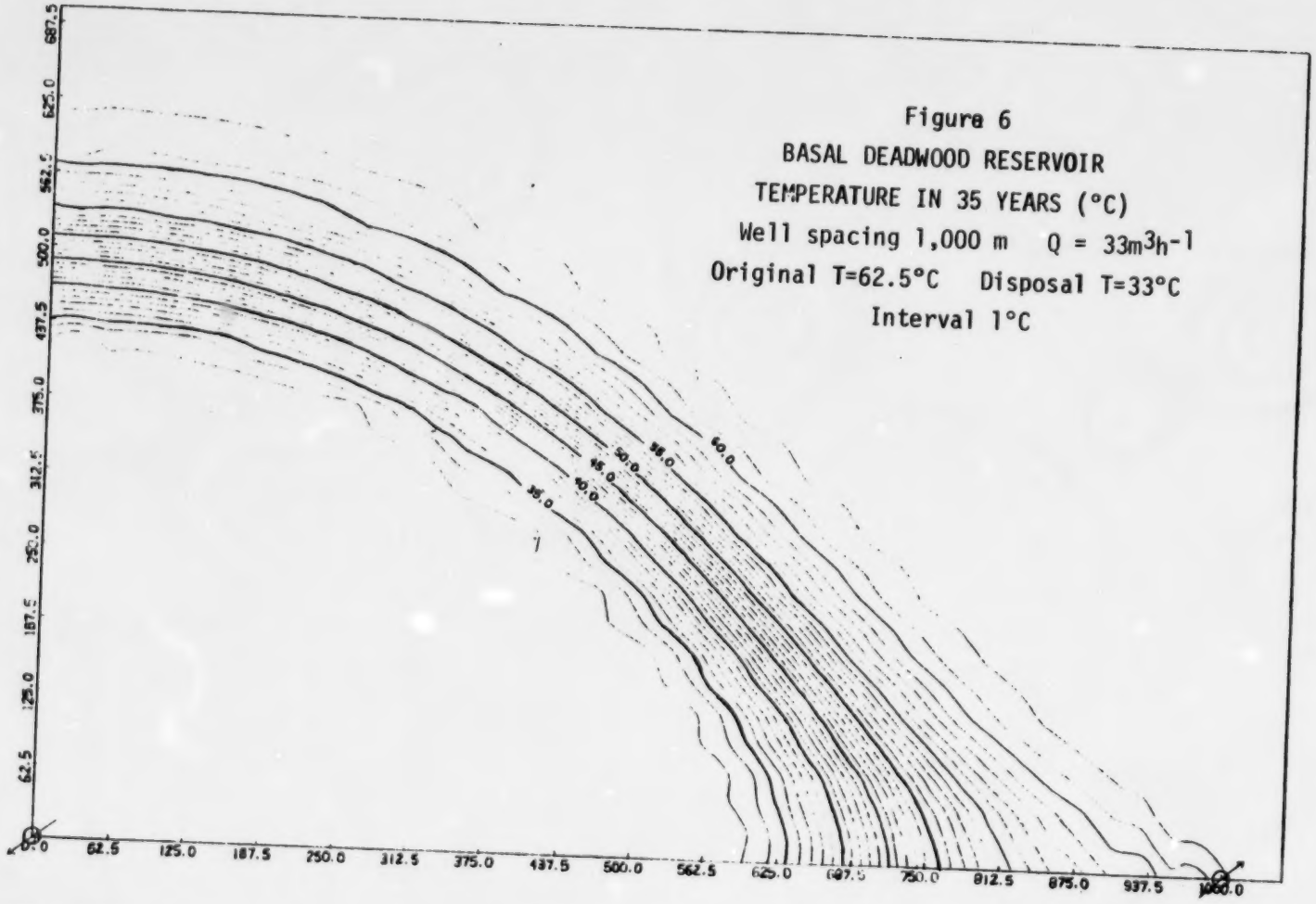


Figure 6
BASAL DEADWOOD RESERVOIR
TEMPERATURE IN 35 YEARS (°C)
Well spacing 1,000 m Q = 33m^3h^{-1}
Original T=62.5°C Disposal T=33°C
Interval 1°C

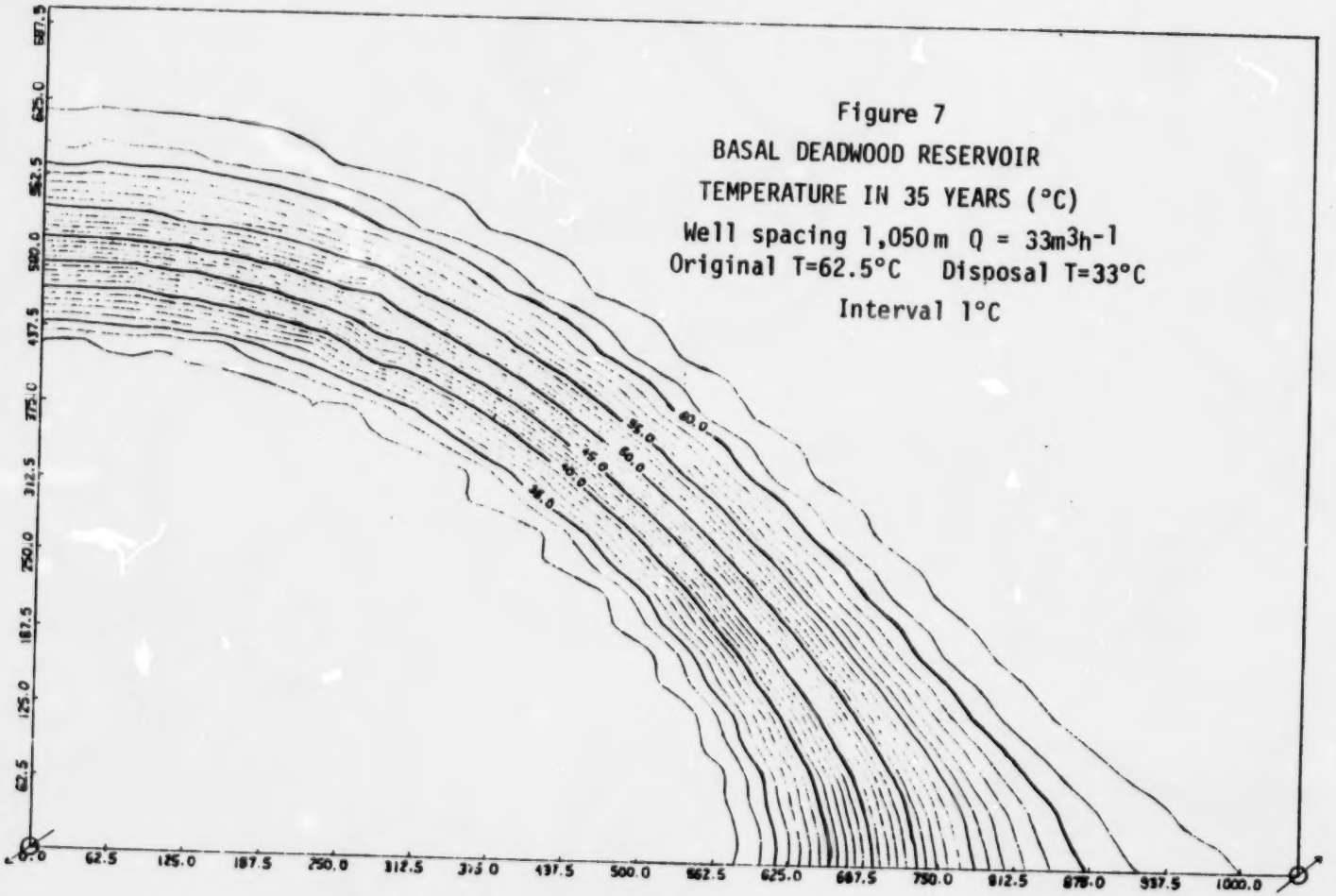


Figure 7

BASAL DEADWOOD RESERVOIR

TEMPERATURE IN 35 YEARS (°C)

Well spacing 1,050 m Q = 33 $m^3 h^{-1}$

Original T=62.5°C Disposal T=33°C

Interval 1°C

between wells is 975 m for Figure 5, 1,000 m for Figure 6 and 1,050 m for Figure 7.

For a well spacing of 975 m (Fig. 5), the model shows some instability around the production well but the "cooled front" has certainly arrived and the Basal Deadwood production temperature has probably been reduced to about 60°C. Because the Basal Deadwood produces one-third or less of the Basal Clastic Unit water, the average production temperature should not be reduced more than about 1°C. At a spacing of 1,000 m (Fig. 6), the expected temperature reduction in produced water is less than 0.5°C after 35 years. At a spacing of 1,050 m, the cooled water is still at some distance from the production well after 35 years (Fig. 7).

One other consideration examined in well modelling work was the implications of regional flow in the aquifer (a "favourable" flow from production well toward injection well or an "unfavourable" flow from recharge to discharge). Under the regional hydraulic potential gradients likely to be present (2.5 m per km) and considering the distance between wells (1 km), it was found that the regional flow was not significant in determining the optimum distance between wells. With a "favourable" reqional flow, the distance between wells could be reduced by less than 10 m as compared to the optimum spacing with "unfavourable" flow.

4.3.3 Conclusions regarding well spacing and alternative sites for disposal well.

To minimize pipeline costs, to maximize benefits of "lift" at the producing well, and to keep within temperature restraints (2°C temperature drop in 35 years), it is concluded that 1,000 m would be an optimum distance between the producing and disposal well. The minimum well spacing should not

be less than 975 m. A suggested maximum distance is 1,025 m to minimize costs and maximize benefits.

Our original intention was to locate the disposal well 1,830 m distant in Lsd. 1-6-17-19 W 2M. The models supply excellent documentation that it is neither necessary nor desirable to have a well spacing in excess of 1,025 m. Three alternative sites at 1,000 m distance are shown in Figure 8. Advantages and disadvantages of the three sites are:

Site No. 1 in Lsd 10-8-17-19

General

Situated at the northeast end of University of Regina land, 208 m from Wascana Creek and 95 m from waterfowl preserve. Freehold minerals (Ross Estate) under lease to Univ. of Regina.

Advantages

1. On University of Regina land, ready access in foreseeable future.

2. Shortest and simplest pipeline route (975 m from Heating Plant), all on University land, no highway crossings.

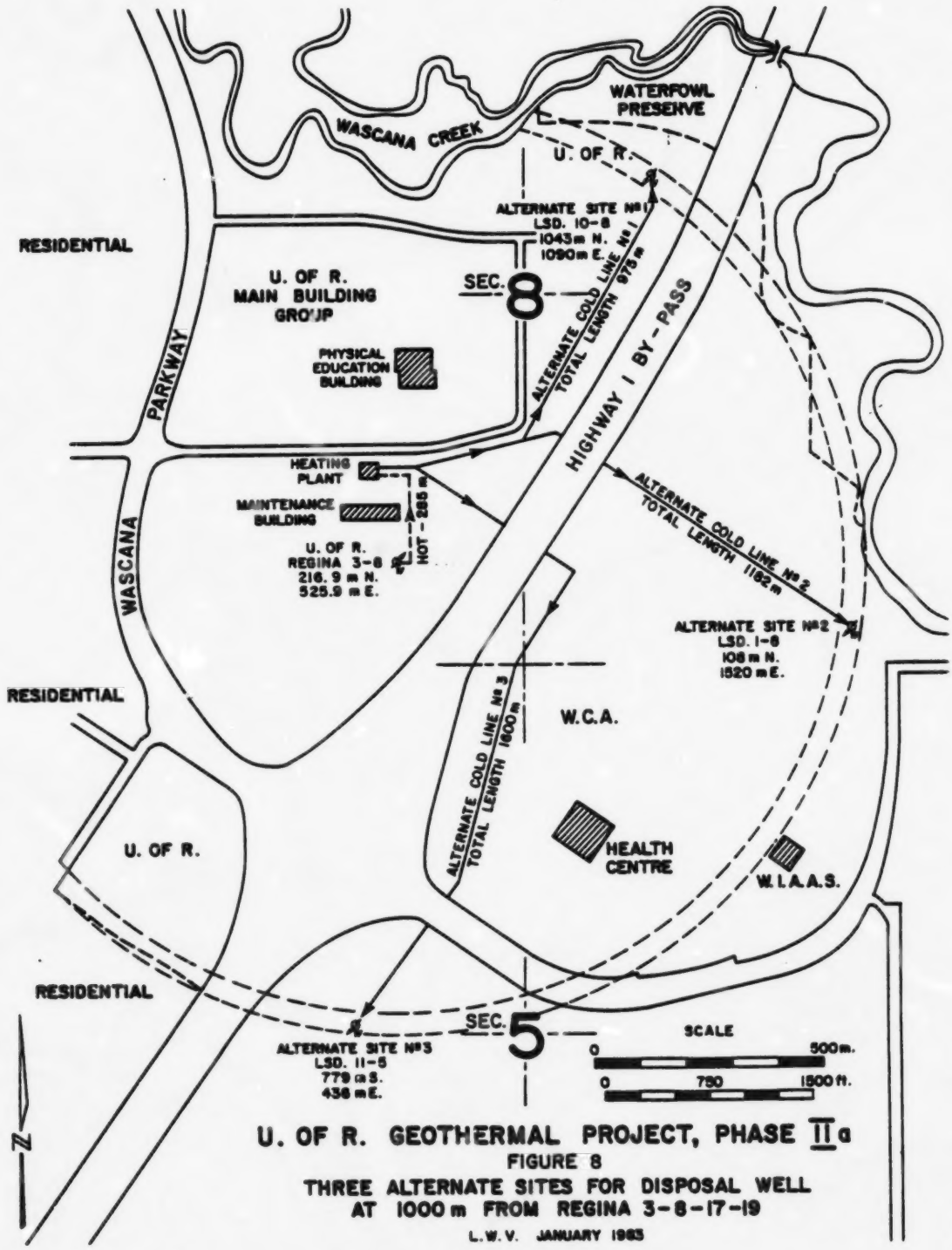
3. Regional flow in aquifer from U of R 3-8 well is favourable. (This advantage believed to be very minor).

Disadvantages

1. Proximity to Wascana Creek and bird sanctuary. Prohibitions do not appear to be in effect but diking may be desirable or required.

2. The site has not been surveyed by seismic and there is a slight risk of encountering a salt-solution feature (as is present at the Imperial 4-32-17-19 well, 5.6 km to the north). An old seismic line (in secs. 11, 15 and 16) situated 2.2 km to the northeast of the proposed location (Surjik, 1978) indicates that one would not expect a salt solution feature.

Figure 8 - Three alternative sites for disposal well



Site No. 2 in Lsd 1-8-17-19

General

Situated on Wascana Centre Authority land, 500 m north of the Wascana Institute of Applied Arts and Science, 95 m from Wascana Creek, 100 m from road to Wascana Country Club. Freehold minerals (Ross Estate) under lease to U of R.

Advantages

1. Ready access.
2. Intermediate pipeline route (1182 m) from Heating Plant, one highway crossing.
3. Regional aquifer flow probably favourable (very minor advantage).

Disadvantages

1. Proximity to Wascana Creek and golf course. Probably requires diking
2. Proximity to farmhouse.
3. Length of pipeline, one highway crossing.
4. Not on University land.

Site No. 3 in Lsd 11-5-17-19 W 2M

General

Located on Wascana Centre Authority land 400 m southeast of centre of interchange of Highway No. 1 By-pass with Wascana Parkway. Saskatchewan Crown Minerals (undisposed).

Advantages

1. Distant from creek, no diking required.
2. Reasonable access from Wascana Parkway.
3. Plenty of room for site selection.

Disadvantages

1. Long pipeline route (1600 m) with two highway crossings.
2. Regional flow probably unfavourable (negligible disadvantage).
3. Not on University land.

It is recommended that one of these alternate sites be chosen for the disposal well. We strongly recommend Alternate Site No. 1 (Lsd 10-8). If this site is not acceptable, we recommend Alternate Site No. 3 (Lsd 11-5), closely followed by Alternate Site No. 2 (Lsd 1-8).

4.4 Task 4: Obtain permission to dispose.

On July 6, 1981, the University of Regina applied to the Minister of Mineral Resources to dispose of salt water into the Basal Clastic Unit in a well to be drilled in Lsd. 1, Sec. 6. Tp. 17, Rge. 19 W 2M. A copy of the approval, dated 31 August 1981, is included as Appendix V.

We propose to re-locate the disposal well at a new location. An amendment to the ministerial order will be required.

4.5 Task 5: Acquire minerals and acquire a surface lease.

On the presuppposition that the disposal well would be drilled in Lsd 1-6-17-19 W 2M, Mr. R.N. Millar acquired on behalf of the University of Regina a lease and grant on petroleum and natural gas on the following:

a) NE 1/4-31-16-19 W 2M - lessee N.E. Whitmore

b) NE 1/4-32-16-19 W 2M - lessee A.H. Sattler

Both instruments have effect from April 23, 1982.

Because the well proposed for Lsd 1-6 would be on Wascana Centre Authority land, permission is necessary but a surface lease is not required.

The proposed well in Lsd 1-6 would have been a direct offset to Lsd 16-31-16-19 W 2M and a diagonal offset to Lsd 13-32-16-19 2M. Offsets to the newly proposed locations are:

a) Lsd 10-8-17-19 W2 - Offset by Wascana Centre Authority land (Sask. Crown?). Other nearby parcels are fragmented.

b) Lsd 1-8-17-19 W2 - Offset to east and southeast by undisposed lands of City of Regina, Wascana Country Club, and Canada Crown. Offset to the south by McKenzie Estate leased to the University of Regina.

c) Lsd 11-5-17-19 W 2M. Offset to the north by McKenzie Estate mineral lands leased by the the University of Regina.

Presuming that we will select one of these locations for drilling the dispcsal well, we recommend that we do not attempt to lease the offsetting mineral leases.

4.6 Task 6: Obtain permits and right of way for pipeline between proposed producing and disposal well.

I.A. Nattress and L.W. Vigrass held discussions with Messrs. J. Moran and J.B. Paterson of Wascana Centre Authority regarding this matter. They indicated that, when plans were defined, a pipeline route map should be submitted to the Authority. Our impression was that the plan would be well received.

Similarly Mr. Nattress conferred with officials at the Department of Highways who indicated that a submission to cross the highway right-of-ways would receive sympathetic consideration.

4.7: Design well program and cost estimate.

Mr. D.C. Ruse, P.Eng., prepared on behalf of the University of Regina a well design and cost estimate (Appendix VI). In consultation with Mr. Ruse, we are recommending that the disposal well be drilled into the lower Winnipeg (2,060 m) and longstring casing (essentially 178 mm) cemented in place. The completion through the Basal Clastic Unit will be 159 mm open hole below the casing shoe at 2,060 m. The plan is to drill the hole to 2,060 m on a footage (or possibly a turnkey) basis and complete the lower part of the well on a day rate basis.

Before a final decision is reached on the well program, we should investigate the possibility of running larger diameter casing at the top of the production string (273 mm casing to a depth of 245 m) rather than the 219 mm casing as outlined in the present program. The larger diameter casing would cost more but it might allow us to run a less expensive pump (a TRW Pleuger pump at $40,000 rather than a TRW Reda pump at $125,000). This decision would be based largely (but not entirely) on cost. Until this comparison has been made, we are proceeding on the basis of the designed program (219 mm casing and a Reda pump) with a minor modification: we would recommend setting of 280 m of 340 mm casing so that, if desirable, the production casing can be cut off and a larger pump installed at 240 m depth. Length of the 219 mm casing can be reduced to 245 m but an extra stage collar is required. Extra cost is estimated at $6,500 or 25 percent of the surface casing cost.

In recent conferences, Mr. Ruse has indicated that, because of under utilization of drilling capacity, the cost estimate of September, 1981 is probably valid at present. A summary of the cost is as follows:

Total cost shown by D.C. Ruse	$582,135
Legal survey and deposit	2,500
Additional surface casing	6,500
FST and E & H Tax	25,000
Injection string and packer	68,000
Workover rig and pump test	13,000
Core and water analysis	5,365
Total estimated cost (to wellhead)	$702,500

Task 8: Issue tenders for drilling of disposal well.

This task was not completed because approval for the disposal well was not received. Mr. Ruse prepared on our behalf a Bid Sheet and Well Specifications for Standard Drilling Contract (Exhibit A of Appendix VII). He also prepared specification sheets along with a list of suggested suppliers for:

Cementing and casing accessories
Wellhead
Testing
Coring
Logging
Power Tongs
Directional Survey

These documents are included in Appendix VI.

4.9 Task 9: Select drilling contractor.

This task was not completed because tenders were not issued.

4.10 Task 10: Conduct a pre-design investigation of use of geothermal energy at the University of Regina.

4.10.1 Summary of the Novametric-McCartan report.

Novametric Engineering Inc. and McCartan Gaudet and Associates Ltd. conducted this task on behalf of the University of Regina. Their report "Use of Geothermal Energy Combined with Conventional Energy Sources at the Main Campus University of Regina" is included as Appendix VIII.

The Novametric-McCartan report shows that the geothermal energy can be used in a practical way in several of our present buildings where the retrofit comprises "add-ons" to our present heating system. In at least four buildings, the heat energy can be used in a practical way for direct heating of air (in terminal reheat and dual duct heating, ventilating and air conditioning systems) and for hot water heating (swimming pool heating, domestic hot water heating, and make-up boiler feed water heating). The subcontractors recommend an option to use the geothermal heat in the Heating Plant, Physical Education, College West, and Administration-Humanities Buildings. In the last three buildings, the geothermal energy could be used directly in the mechanical rooms with no necessity to circulate the secondary circuit water (fresh water) throughout the building space. Above a temperature of -20°C (all but 900 hours annually), the geothermal system could supply virtually all the heat required for the retrofitted systems. Below -20°C the existing steam-based system would supplement the geothermal system.

The Novametric-McCartan report indicates that, over the course of a year, the four retrofits would utilize about $36{,}000 \times 10^{-6}$ Btu. This is about 38% of the $94{,}000 \times 10^{6}$ Btu/yr that comprise the present campus heating load. If the geothermal well doublet was to run at design capacity ($100\ m^3h^{-1}$) for

365 days per year and removed the heat from 58.5°C down to 33°C, about 85,000 x 10^6 Btu/yr, would be available at the main heat exchanger. Assuming 15 percent distribution losses, about 72,000 x 10^6 Btu/yr of geothermal energy could be available at building sites if the system could be run at full capacity.

The Novametric-McCartan report presents in some detail the additional electrical energy costs associated with the geothermal retrofit (mostly pumping costs at the producing and disposal well) and the costs of operating the geothermal system. Capital costs exclusive of the wells and well side systems are estimated. The pipeline costs (distribution system) are the main capital cost with the cost of building retrofit being small in comparison.

In the Novametric-McCartan study, the cost of out-of-plant steam is calculated to be $4.29 per million Btu and the savings realized at the different retrofitted buldings are calculated on this basis. Electrical costs for pumping are based on year-round operation. On this basis, if energy costs just follow the inflation rate, the economic case for retrofit is questionable. Under these same very stringent conditions, however, if it is assumed that energy prices increase at 20 percent per year, the general rate of inflation is 10 percent per year, and the cost of capital is 15 percent per year, the four-building retrofit would net a surplus of $1,600,000 in constant (1982) dollars over a period of 15 years. This is based on a capital cost of $630,000 amortized over 15 years at 15 percent interest. This capital cost does not include the cost of the wells or the well side system.

4.10.2 Reassessment of economics in the Novametric-McCartan report.

On a somewhat different basis than that used by Novametric-McCartan, it is concluded that heat delivered to University of Regina Main Campus buildings

should be credited with a natural gas savings of $5.45 per million Btu rather than their stated figure of $4.29 per million Btu. This is based on pages 2-13 to 2-16 of the Novametric-McCartan report:

A. Cost of gas for a typical year $513,000
B. Delivered as building heat 94,000 x 10^6 Btu
Cost of delivered heat energy = A B = $5.46/$10^6$ Btu [1]

Our analysis would indicate that there is a considerable advantage to operating the geothermal system on less than a full year system. For example, if it was operated similar to our present heating system (say between September 21 and May 21 only) it would result in a 34 percent reduction in extra electrical costs but the delivered energy would be reduced only from 36,446 x 10^6 Btu for a full-year system to an estimated 32,200 x 10^6 Btu for an eight-month system. It is probable that a finer adjustment of the length of season could be made.

An important adjustment to the cost of extra electrical energy for pumping on the well side system (production and disposal well) can be made as a result of optimizing the distance between wells. If the wells are spaced 1,000 m apart, our calculated reservoir drawdown is 140.5 m. With adjustment for friction in the open hole casing, tubing, a 152 mm pipeline, and the main heat exchanger, the total head loss throughout the system is 430 m. The total power required is 124,000 Js^{-1} or 155 kW at 80 percent efficiency.

These adjustments result in the following analysis for a four-building retrofit (Compare to p. 4-8 to 4-13 of Novametric-McCartan report):

1/ If delivery losses are 15 percent, about 1.8 x 10^6 Btu of geothermal energy have to be picked up at the main heat exchanger to deliver 1 x 10^6 Btu at the buildings. There is some argument in favour of a somewhat lower credit rate than $5.46/106 Btu because if steam delivery rates are lowered there is not likely to be a corresponding reduction in distribution and heating plant losses for steam.

ANNUAL ENERGY SAVINGS (OPTION A)(X 10^6 Btu)	
Geothermal loads (8-month season)	32,200
Less	99
	32,101
Projected net savings at \$5.46/10^6 Btu	\$175,000/yr.
LESS: ADDITIONAL ELECTRICAL ENERGY REQ'D:	
	KWH/yr.
(1-4) Heating Plant, Phys. Ed, Admin-Hum	376,042
(5) Distribution System (0.66 x 175,000)	115,500
(6) Well-Side Systems	
(155kW x 5782 hrs)	896,200
Total additional electrical energy	1,387,742
Projected extra cost \$0.0395/kwh	\$54,800
NET ENERGY SAVINGS	\$120,200
Total annual operating costs	39,800
NET ANNUAL SAVINGS	\$ 80,400
CAPITAL COSTS (Option A) (well-side system not included)	
Distribution system	\$465,000
Building retrofits	165,000
CAPITAL COST (1982 dollars)	\$630,000

With the economic assumptions of Novametric-McCartan Case 1 (p. 4-14 - 4-17), the present value of the surplus in 15 years would be over \$3,000,000 in 1982 dollars with the cost of retrofit completely retired.

If natural gas and electricity cost escalate only at the same rate as inflation (Novametric-McCartan Case 2), the case is not as favourable but the present value of the surplus is positive after 15 years (about $250,000 in 1982 dollars) with the cost of retrofit retired.

A different approach to economics that has direct relevance to this problem is the "no loss strategy" which defines the maximum investment that should be made to save an annual expense given the lifetime of the cost-saving facility or equipment (see, for example, the Engineering Digest, Sept., 1978, "The cost of saving regular costs"). The maximum ratio of capital invested to the first year expense saved (maximum C/S ratio) is mainly dependant on the facility lifetime in years, is dependant to a lesser degree on the difference between the interest rate and inflation rate $[(1 + i) - (1 + f)]$, and is even less dependant on the absolute value of the inflation rate $(1 + f)$. The "no loss strategy" makes allowance for complete retirement of the cost of the facility and for accumulation of funds to replace the facility when its useful life is over.

In the present case, we assume that the worth of energy escalates at the same rate as the general rate of inflation. It seems reasonable that the retrofit will last at least 20 years. If the average inflation rate is 7 percent per year and the average interest rate runs 3 points higher than this (10 percent), then a prudent manager would invest (under the "no loss strategy") up to 8.99 times the first year expense saved: this is the maximum C/S ratio. For the same period (20 years) if the inflation rate is 12 percent and the interest rate 15 percent, the maximum c/s ratio is only marginally reduced to 8.61. For a 20 year lifetime and for expectable inflation rates (3 to 15 percent) and expectable differences between interest rate and inflation rate (difference 2 percentage points to 6 percentage points), the maximum C/S ratio ranges from 7.81 to 9.50. For our case of the Option A retrofit, the

C/S ratio has the very acceptable value of 7.8 ($630,000 $80,300 = 7.8). If the lifetime is increased to 35 years for the same inflation and interest rates, the permissible C/S ratios are increased to range from 11.86 to 16.22, well above the C/S ratio of 7.8 that applies to the Option A retrofit.

4.10.3 University of Regina recommendation from the Novametric-McCartan study.

Even though it is technically and economically feasible for the University to use the energy at the four locations (Option A of Novametric-McCartan), we recommend that a retrofit to geothermal energy be done only at the Heating Plant and the Physical Education Building. Both buildings will retain their present steam system as backup. Justification for completion of the Regina Geothermal Project is based largely on its value as a research, development, and demonstration project (see later sections of this report). The reasons for retrofitting only two buildings are:

1) The two buildings will use a sufficiently large proportion of the energy available from the two well system to serve as a good demonstration

2) It is probable that additional University buildings will be constructed in the southeast part of the Campus during the next few years. The new building or buildings would be designed to use the geothermal source as the primary heating mode. We believe that this approach is desirable both from a demonstration and economic standpoint.

We would propose that the system be run only during the period approximating September 21 to May 21 when the average temperatures are generally below 15°C. The geothermal loads below 60°F (15.6°C) are summarized in Table 6 (from Novametrics-McCartan report, p. 4-4).

Table 6: Geothermal load summary - Heating Plant and Physical Education Buildings (10^6Btu/hr.)

	°F-45	-35	-25	-15	-5	5	15	25	35	45	55
Heating Plant	1.23	1.11	1.00	.88	.77	.66	.54	.43	.31	.20	.09
Physical Education	3.99	3.74	3.45	3.19	2.92	2.63	2.38	2.09	1.83	1.55	1.26
Totals	5.22	4.85	4.45	4.07	3.69	3.29	2.92	2.52	2.14	1.75	1.35

The maximum load plus distribution losses (15 percent of total) amounts to 6.14 x 10^6 Btu/hr or 1.8 MW. This is about 60 percent of the nominal capacity of the geothermal doublet. It could be supplied by a pump yielding about 60 m^3/h of 58°C water with power input of 45 kW.

Following is the analysis of the two building retrofit (see Novametric-McCartan Rept., p. 4-9 to 4-13):

ANNUAL ENERGY SAVINGS (TWO BUILDINGS)

Geothermal loads 18,350 x 10^6 Btu/year	
Projected net savings at \$5.46/10^6 Btu	\$100,000
LESS: ADDITIONAL ELECTRICAL ENERGY REQUIRED	
	kWh/year
Heating Plant, Physical Education	230,000
Distribution system (10 kW x 5,782 hr)	57,800
Well side system (0.6 x 155 kW x 5782 hr)	537,800
Total additional electrical energy	825,600
Projected extra cost at \$0.0395/kWh	\$ 32,600
NET ENERGY SAVINGS	\$ 67,400
Total annual operating costs	25,800
NET ANNUAL SAVINGS	\$41,600
CAPITAL COSTS - TWO BUILDINGS	
(Well-side system not included)	
Distribution system	\$191,000
Building retrofits	107,000
	\$298,000

For the two building system, the ratio of capital invested to the first year expense saved (C/S ratio) is 7.2. This is quite acceptable as a University investment if the facility is expected to last 20 years or more.

A projected cash flow has not been prepared.

4.10.4 Submission regarding funding for secondary circuit and retrofit

The Director of Physical Plant, Mr. Tom Tribe, has included $300,000 for the distribution line and retrofit of the Heating Plant and Physical Education Building in his budget requests ($200,000 for 1983-84 and $100,000 for 1984-85). These budget requests are currently being reviewed by the University of Regina Board of Governors and the Saskatchewan Universities Commission.

4.11 Task 11 Prepare a final report

This requirement is fullfilled by this document.

A detailed work statement and a detailed cost breakdown for Phase IIb of the project are included as Appendix IX.

4.12 Task 12 Present a paper at international converence.

L.W. Vigrass attended the International Conference on Geothermal Energy at Florence, Italy, May 11-14, 1982, and presented a paper "Geothermal Energy from the Williston Sedimentary Basin at Regina, Canada". A reprint of the paper is included as Appendix X.

Sessions of the Conference of particular interest included: B) Exploration and Development; C) Modelling and Reservoir Evaluation; D) Drilling, Production and Testing; E) Corrosion, G) Low temperature, Non-Electric Uses. L.W. Vigrass has a copy of the Conference Proceedings (Vol 1 and 2).

L.W. Vigrass conferred with Dr. J.D. Garnish, Energy Technology Support Unit, Harwell, U.K. and Mr. D.A. Gray, Assistant Director of the Institute of Geological Sciences, London, U.K.

5. DISCUSSION OF RESULTS, SUCCESSES AND PROBLEMS

Major objectives of the Regina Geothermal Project are to adapt technology and energy management techniques so that the immense local geothermal resource can be utilized under western Canadian conditions. In this respect, the main accomplishments of Phase IIa fall under Task 3 (Identify site for disposal well) and Task 10 (Usage study). Successful development of a mathematical-computer model for well spacing and application of this model to the Regina reservoir has allowed us to pick a new site for the disposal well that is much closer to the production well than our original proposal. This will reduce the cost of the pipeline and simplify construction considerable, especially if Alternate Site No. 1 is used. The closer spacing of the two wells will also reduce the capital and operating costs of pumping at the discharge and recharge wells. The usage study has shown that it is technically feasible to retrofit four of the main university buildings by making changes that are largely confined to the mechanical rooms. The retrofits themselves have a relatively low cost (est. $165,000) with the cost of the distribution lines considerably higher ($465,000). If wellside capital costs are not included,

it is economically desirable to retrofit the buildings. We have recommended retrofitting only two of the four buildings so that geothermal capacity from the doublet is available to install in a future new building or buildings where the geothermal energy can be installed from the ground up.

An additional noteworthy success associated with Phase IIa was the installation of cathodic protection with anode test beds and other assessment features.

Problems unresolved or only partly resolved by Phase IIa include:

1) Power requirements for a pump at the Regina 3-8 well will be about 60 kVA. The present system can only supply 25 to 30 kVA.

2) At the Regina 3-8 well, water level monitoring over lengthy periods of time was not possible with the system installed. It is desirable to continue this work (for basic research and to verify determinations of aquifer parameters) and we are cooperating with Saskatchewan Research Council in this regard.

3) Monitoring should be continued on the cathodic protection system over the next few years.

4) Additional work on aquifer behaviour is desirable. Commencing January 1, 1983, we are cooperating on some of this work with Walter Jones, University of Alberta.

5) If a new well location is chosen, an amendment to our present permit to dispose is necessary.

6) Permission of Wascana Centre Authority to conduct operations under Phase IIb will be required. This can be obtained only when plans are firmed up.

7) A final decision must be reached on size of casing at the top of the production string.

8) A drilling contractor and suppliers of materials and services have not been selected.

9) On receipt of approval to proceed, design of the wellside system (pumps, piping, heat exchanger, controls) must be finalized and integrated with design of the secondary system and building retrofits.

6. RECOMMENDATION REGARDING CONTINUANCE OF WORK

Low-grade geothermal energy is being used elsewhere in the world for space heating, water heating, greenhouses, industrial processes and drying, and various other low-grade energy applications. The Canadian and Saskatchewan resource, which ranges greatly in quality from place to place, is immense and widely distributed. The Regina Geothermal Project has the main objectives of investigating and demonstrating usage of this huge energy resource under western Canadian conditions. The Regina Geothermal Project was and is intended to pave the way for the usage of low-grade geothermal energy 1) in situations where the installation cost can be lowered because geothermal energy is installed from the ground up rather than as a retrofit, 2) in situations where the utilization factor is high, and 3) in parts of Saskatchewan and Canada where the geological conditions are more favourable (higher geothermal gradient or deeper parts of the sedimentary basin). It is also our conviction that we should be examining what the relative merit of geothermal energy versus fossil fuels will be several years from now: we are convinced that because of inherant scarcity and despite the current surplus of oil and gas, fossil fuel prices will continue to escalate at a rate greater than the general rate of inflation. With geothermal energy, as with other energy technologies, a minimum of several years of research, development and

demonstration are required before the technology is accepted by the general technical community.

6.1 Assessment of geothermal energy as a primary heating mode built into a facility at the time of construction.

A great many unknowns enter into this assessment. One factor thaat is clear from the Novametric-McCartan study is that the secondary circuit distribution costs can be very significant:there is a distinct economic advantage in having the building load located as close as possible to the main heat exchanger. Another factor is the type of building to be heated and the nature of the load. If the building were a field house or a building with gymnasium type of space, it is expected that forced air heating with high ventilation rates would be desirable. This type of load would be ideal for low-temperature geothermal heat where heating coils with forced air are much superior to radiant surface heating. In this case, the in-building cost of a geothermal heating installation using forced air with heating coils would not be much greater than a conventional heating system (J.J. McCartan, personal communication). Some provision would have to be made for standby heat (in case of failure of the geothermal system) and possibly for some peak loads during the coldest weather.

An excellent sort of load where geothermal energy is the prime heat source installed "from the ground up" would be a 9,300 m^2 (100,100 ft^2) field house situated south of the Physical Education Building and 120 m from the Heating Plant. The estimated cost of such a building is $10,700,000 and the estimated cost of conventional heating equipment (10%) would be $1,070,000. The additional cost of installing steam standby in combination with geothermal would probably be less thatn $60,000 (6 percent of conventional equipment cost).

6.2 Assessment of geothermal energy in more favourable parts of Saskatchewan and Canada.

Other parts of Canada -- for example the Estevan-Weyburn area of Saskatchewan, parts of western Alberta, and northeastern British Columbia -- are much more favourably located than Regina for low-grade geothermal energy. In the southeastern part of Saskatchewan (Estevan-Weyburn area) there is a very sizeable area where the depth to Basement is over 3 km (Vigrass, 1982, Fig. 2). In the same region, the increase of temperature with depth (or geothermal gradient), which is well known from producing oil wells, is 35°C to 40°C per km (Majorowicz and Jessop, 1981, Fig. 5). The result is that the Basal Clastic Unit, which lies immediately above Basement, contains water at 100°C or more over sizeable areas. The reservoir properties of the Basal Clastic Unit have not been assessed in detail in this area but there are probably places where these properties are as good or better than they are at Regina.

With the background that we now have, it is useful to analyse in a preliminary manner the economics of a geothermal project in the Estevan-Weyburn region that has a favourable load factor and where the nergy is used for space heating of large facilities (non-retrofit). Such an analysis is presented in Table 7.

Table 7: Preliminary economic analysis of geothermal project in the Estevan-Weyburn area of Saskatchewan

Assumptions:

Depth of 2 wells	3,000 m
Reservoir and water properties:	Same as Regina 3-8

Water yield, temperature 100 m^3h^{-1}, 98°C at wellhead

Operates 8 months/year, load factor 85 percent

Simple heat exchanger, 33°C reject temperature

Distribution losses 15 percent

Cost of alternative delivered energy \$5.46/10^6 Btu

Additional electrical energy required

Wellside system 155 kW x 5782 hrs/year or 900,000 kWh/year

Secondary system in buildings and distribution is prorated to energy usage at one-half of retrofitted usage for an amount of 7.5 kWh/10^6 Btu.

Annual operating costs (U of R basis)

\$40,000/yr for 36,000 x 10^6 Btu/yr or \$1.11/10^6 Btu/yr.

Capital costs - wellside system

2 cased wells to 3,000 m	\$2,000,000
(U of R wells to 2,200 m estimated total \$1,300,000)	
Injection string and packer	86,000
Submersible pump	125,000
Pipeline, controls	150,000
Heat exchanger	125,000
Power supply, contingency	14,000
Total wellside system	\$2,500,000

Extra capital costs-secondary system

The extra capital cost for geothermal plus standby is six percent of the conventional cost. The added distribution cost for the Estevan-Weyburn system is estimated to be the same as the U of R system (\$500,000).

ENERGY AVAILABLE

At main heat exchanger:

$27.8\ kgs^{-1} \times (98 - 33)K \times 4{,}186\ J/kg\text{-}K$

$= 7.56 \times 10^6 Js^{-1}$

$= 7.56\ MW$

$7564\ kW \times 1\ Btu\ s^{-1} / 1.054\ kW = 7{,}176\ Btu\ s^{-1}$

Delivered energy:

$7176\ Btu\ s^{-1} \times 0.85 = 6{,}100\ Btu\ s\text{-}1$

$= 22 \times 10^6\ Btu/hr.$ [1]

Annual delivered energy:

$22 \times 10^6\ Btu/hr \times 5{,}782\ hr/yr \times 0.85 = 108{,}000 \times 10^6\ Btu/yr$ [2]

Value at $\$5.46/10^6$ Btu $\$590{,}000/yr$

[1] The heating load at the University of Regina Main Campus is approximately 22×10^6 Btu/hr at -19°C (-2°F).

[2] The average total delivered heat energy for the Main Campus, University of Regina (7 major buildings, 3 smaller buildings) is $94{,}000 \times 10^6$ Btu/yr

ADDITIONAL ELECTRICAL ENERGY REQUIRED - kWh/yr.

Wellside system	900,000
Secondary system	
$7.5\ kWh/10^6\ Btu \times 108{,}000 \times 10^6\ Btu/yr$	810,000
	1,710,000

Additional electrical energy cost @ $0.0395/kWh = $67,545/yr

NET ENERGY VALUE $522,500/yr

OPERATING COST

$1.11/$10^6$ Btu x 108,000 x 10^6 Btu/yr = $120,000/yr

NET SAVINGS/YR $402,000

CAPITAL COST SUMMARY

Wellside system	$2,500,000
Extra in-building cost	
0.06 x $119/$10^6$ Btu/yr x 108,000 x 10^6 Btu/yr	770,000
Extra distribution costs	500,000
Total chargeable capital cost	$3,770,000

CAPITAL COST/1ST YEAR SAVINGS = 9.38

In Table 7, the chargeable capital consists of the wellside system (including wells) plus the capital expenditures that must be made on the heating system itself in excess of what would have been required for a conventional (fossil fuel) system. The table shows that the ratio of chargeable capital costs to first year net savings (C/S) is 9.4, a reasonable value of C/S ratio for a 20-year investment using the "no loss" strategy.

Table 8 shows a 15 year cash flow projection for a geothermal doublet in the Estevan-Weyburn area under the following assumptions:

1) the general inflation rate is 10 percent per year

2) natural gas and electricity costs escalate at the inflation rate (10 percent)

3) capital costs are amortized over a period of 15 years at an interest rate of 15% per year.

Note that, in this scenario, the capital costs (including drilling and all well side costs) will have been retired in 15 years and the "PV Surplus" column expresses the surplus in 1983 dollars.

With energy costs escalating at the same rate as general inflation, the present value of the surplus at the end of the amortization period (15 years) is $575,000 (compare with Novametric-McCartan report, Option A, Case 2). Because the capital cost has been retired after 15 years, a large surplus will accumulate for the remiander of the life of the project.

We have also explored the economic situation with the economic parameters the same as the Novametric-McCartan Option A, Case 1 (p. 4-14 to 4-16), namely: 1) the general inflation rate is 10% per year

2) natural gas prices escalate at 22.8% and electricity costs escalate at 18.2% per year,

3) capital costs are amortized over a 15 year period at an interest rate of 15% per year.

In this case, the net savings escalate at approximately 32.6% per year. At the end of 15 years, when all capital costs (including all drilling and wellside costs) amounting to $3.8 million have been retired, the present value of the surplus is more than $20 million.

TABLE 9: Projected cash flows in thousands of dollars, geothermal doublet, Estevan-Weyburn area (See text for parameters and assumptions).

Year	Net Savings	Capital Costs	Surplus	PV Surplus
1	402	645	(243)	(221)
2	442	645	(203)	(168)
3	486	645	159	(119)
4	535	645	(110)	(75)
5	589	645	(56)	(35)
6	647	645	2	1
7	712	645	67	34
8	783	645	138	64
9	862	645	217	92
10	948	645	303	117
11	1043	645	398	139
12	1147	645	502	160
13	1262	645	617	179
14	1388	645	743	196
15	1527	645	882	211
	12,773	9,675	3,098	575

These analyses show that for this particular example the economics of geothermal energy are reasonably favourable if energy prices escalate at the same rate as inflation. If energy prices were to increase at a considerably faster rate, the economics would be extremely favourable.

It is reasonable to expect that the geological conditions described in the Estevan-Weyburn area are present over a large area in southern Saskatchewan, western Alberta, northeastern British Columbia, and elsewhere in Canada. With installation of geothermal energy in sizeable facilities from the "ground up" and a reasonably large load factor, the economic potential for geothermal energy in favourable geological areas is very good indeed.

The Regina Geothermal Project should be continued in order to investigate and demonstrate usage of this energy under Canadian conditions.

7. PROPOSAL FOR PHASE IIb

It is proposed that we complete Phase II (Installation of the wellside system) and proceed with Phase IIIa (Demonstration of geothermal usage in retrofitted Physical Education and Heating Plant Buildings) A work statement and cost breakdown is included as Appendix IX

The estimated cost for Phase IIb is $1,150,000 and for Phase IIIa is $350,000.

Work would commence on Phase IIb as soon as authorized and be completed by October 31, 1983. Work on Phase IIIa would be conducted during Summer 1983 and Summer 1984.

8. CONCLUSION

Usage of the immense, widely-distributed resource of low-grade (sedimentary) geothermal energy would be beneficial to Saskatchewan and Canada. Development of this resource is technically feasible. In geologically favourable areas, usage is economically viable now or will be in a few years as the price of hydrocarbon fuels increases relative to other commodities. Objectives of the Regina Geothermal Project are to investigate, develop, and demonstrate usage of the resource. The project has significant potential value to the province and the nation. The program of investigation should be continued by completion of the wellside system (disposal well and pipeline) and installation of a retrofit demonstration in two buildings on the University of Regina Campus.

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